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2D-Confined Nanochannels Fabricated by Conventional Micromachining

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ABSTRACT

Two new methods have been developed to fabricate nanochannels by conventional micromachining. We succeeded in restricting the width of the channels to the submicrometer scale, while using standard photolithography with a resolution in the order of 1 μm. The first method is based on the sacrificial etching of a nanowire, which was formed on the side wall of a step. The second method is based on the adhesion of the capping layer to the substrate after removal of a sacrificial strip separating the two. The fabricated nanochannels are localized and can be connected to microchannels and reservoirs.

We report two new methods to fabricate channels, which are confined in both height and width to submicrometer dimensions. Both methods are based on sacrificial layer etching, which is a well-established technique for the monolithic fabrication of micro- and nanofluidic devices.[1−4] The essence of the technique is the selective removal of the patterned sacrificial layer to create the inner space of a fluidic channel, leaving the surrounding material to constitute the walls of the channel. For example, Stern et al.[1] fabricated 2 mm long nanochannels with heights in the range of 20−100 nm by sacrificial etching of amorphous silicon in a TMAH solution. The reported channels[1−4] are confined to the submicrometer scale only in the height. The channel width is in the micrometer range, the lower limit determined by the resolution of the photolithographic process used. We succeeded in confining the channel width to the submicrometer scale as well, while using standard photolithography with a resolution in the order of 1 μm. A similar approach but a different method was reported by Schmidt and Eberl.[5]

Referring to Figure 1A, in method one a channel is created on the side wall of a submicrometer step. First, a nanowire is created on the side wall of the step.[6−8] This sacrificial nanowire is covered by conformal deposition of a capping layer. Finally, the capping layer is opened at both ends of the sacrificial nanowire, and the wire is etched away to create the nanochannel. The height of the nanochannel is determined by the height of the initial step, the width approximately by the thickness of the sacrificial layer. Figure 1B shows a scanning electron microscope (SEM) photograph of a fabricated nanochannel, having a height of approximately 90 nm and a width of approximately 40 nm. The channel was formed by etching of a sacrificial polysilicon wire. It has a length of 0.64 mm after 15 h of etching in a 25 wt % aqueous KOH solution at 75 °C. The channel walls consist of silicon nitride, grown by low-pressure chemical vapor deposition (LPCVD). Both the step and the sacrificial wire were created by directional reactive ion etching (RIE).

Method two is based on the adherence of the capping layer to the bottom layer, after removal of a sacrificial strip (Figure 1C). The capping layer is brought into contact with the bottom layer by capillary forces during drying of the structure. Once brought in contact, the two layers can permanently adhere[9,10] and a nanochannel is formed. If the capping layer deforms elastically, the channel width x is found by minimization of the free energy, consisting of the surface free energy and the elastic energy of the deforming layer:[11]

$$x = \sqrt[4]{\frac{3}{2}\frac{Et^3g^2}{\gamma}} \tag{1}$$

where E is the Young's modulus of the capping layer, t the thickness, g the initial gap between the capping layer and the substrate, and γ the adhesion energy (the lowering of the surface free energy per unit area of contact). Figure 1D shows an SEM photograph of a nanochannel fabricated by method two. It has a height of approximately 50 nm and a

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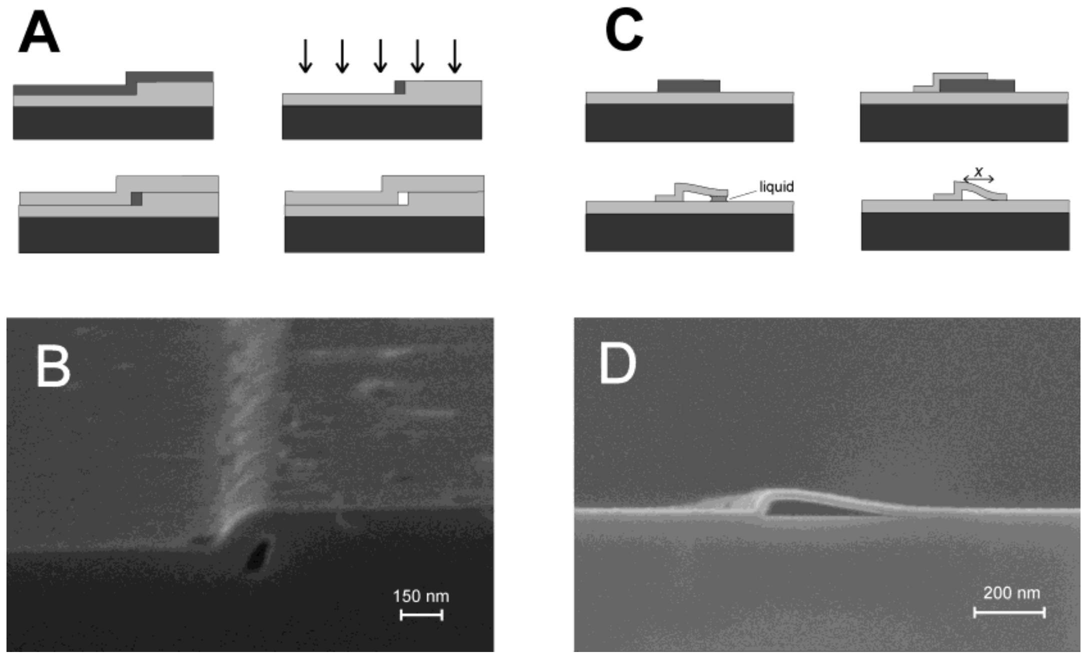

Figure 1. Fabrication of 2D-confined nanochannels. (A) Method one is based on the formation of a nanowire on the side wall of a step. The nanowire is subsequently encapsulated, and finally it is removed by chemical etching to create the nanochannel. (B) SEM photograph of a nanochannel fabricated by method one. The height and the width of the channel are approximately 90 and 40 nm, respectively. (C) Method two is based on the etching of a sacrificial strip separating the substrate and the capping layer. During drying of the structure the capping layer is pulled down by the capillary forces of the remaining liquid, and once brought in contact with the substrate, adheres permanently forming a nanochannel. (D) SEM photograph of a nanochannel fabricated by method two. The height and width of the channel are approximately 50 and 400 nm, respectively.

width of approximately 400 nm. The sacrificial material was silicon dioxide, thermally grown on the silicon substrate wafer. The capping layer is 20 nm of polysilicon, grown by LPCVD. The sacrificial strip was removed by 4 min of etching in a 50% HF solution. The short etching time is possible because the etching is performed sideways, over a distance of only a few micrometers. This is an advantage of method two in comparison with method one, where etching takes place lengthwise. To strengthen the bond between the capping layer and the substrate, the structures were annealed at 1100 °C for 2 h. For a measured channel width x, eq 1 can be employed to estimate the bond strength. Using a Young's modulus $E = 150$ GPa and the dimensions mentioned, eq 1 gives a value $\gamma = 0.2$ J/m^2 for the adhesion energy. This value is in agreement with the range of adhesion energies found in wafer bonding experiments.[12]

The presented methods based on conventional lithography, thin film deposition, and etching offer intriguing possibilities. With some optimization we believe that the width and the height of the nanochannels can be reduced down to the order of 10 nm. The nanochannels are localized, can have large lengths (millimeters), and can be connected to larger channels and reservoirs created by micromachining. They could therefore serve as an important experimental tool for studying capillarity and phase transitions in 2D-confinement.[13−18] Furthermore, due to their small internal volume they could be useful for single-molecule experiments.

References

(1) Stern, M. B.; Geis, M. W.; Curtin, J. E. *J. Vac. Sci. Technol.* **1997**, *B15*, 2887.
(2) Turner, S. W.; Perez, A. M.; Lopez, A.; Craighead, H. G. *J. Vac. Sci. Technol.* **1998**, *B16*, 3835.
(3) Rasmussen, A.; Gaitan, M.; Locascio, L. E.; Zaghloul, M. E. *J. Microelectromech. Syst.* **2001**, *10*, 286.
(4) Foquet, M.; Korlach, J.; Zipfel, W.; Webb, W. W.; Craighead, H. G. *Anal. Chem.* **2002**, *74*, 1415.
(5) Schmidt, O. G.; Eberl, K. *Nature* **2001**, *410*, 168.
(6) Fu, H.-S. U.S. Patent 4,358,340, 1982.
(7) Flemming, J. G.; Lin, S, Y.; *SPIE Conference on Miniaturized Systems with Micro-Optics and MEMS*; Santa Clara, CA, September 1999, SPIE vol. 3878, p 9.
(8) Kim, D. H.; et al. *Appl. Phys. Lett.* **2001**, *79*, 3812.
(9) Guckel, H.; Sniegowski, J. J.; Christenson, T. R.; Mohney, S.; Kelly, T. F. *Sens. Actuators* **1989**, *20*, 117.
(10) Tas, N.; Sonnenberg, T.; Jansen, H.; Legtenberg, R.; Elwenspoek, M. *J. Micromech. Microeng.* **1996**, *6*, 385.
(11) Mastrangelo, C. H.; Hsu, C. H. *Proc. IEEE Solid-State Sensors and Actuators Workshop*, Hilton Head Island (SC), 1992; p 208.
(12) Backlund, Y.; Hermansson, K.; Smith, L. *J. Electrochem. Soc.* **1992**, *139*, 2299.
(13) Ajayan, P. M.; Lijima, S. *Nature* **1993**, *361*, 333.
(14) Dujardin, E.; Ebbesen, T. W.; Hiura, H.; Tanigaki, K. *Science* **1994**, *265*, 1850.
(15) Tsang, S. C.; Chen, Y. K.; Harris, P. J. F.; Green, M. L. H. *Nature* **1994**, *372*, 159.
(16) Ugarte, D.; Chatelain, A.; Heer, W. A. *Science* **1996**, *274*, 1897.
(17) Megaridis, C. M.; Güvenc-Yazicioglu, A.; Libera, J. A.; Gogotsi, Y. *Phys. Fluids* **2002**, *14*, L5.
(18) Koga, K.; Gao, G. T.; Tanaka, H.; Zeng, X. C. *Nature* **2001**, *412*, 802.

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